Transferring Knowledge from Building Operation to Design: A literature review

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TRANSFERRING KNOWLEDGE FROM BUILDING OPERATION TO DESIGN – A LITERATURE REVIEW

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Abstract: As a solution to the previously identified gap between expected and actual building performance, this paper investigates how knowledge can be transferred from operation to design. This is assumed to help bridge the gap and increase the performance of new built facilities. By conducting a systematic literature review, it is found, that the theoretical approach in the reviewed articles has a significant impact on the level of how applicable the recommendations are in practice. Furthermore, a list of identified tools to enable knowledge transfer is provided, including POE, PPP and building commissioning. Knowing that the list lacks inputs from cultural and organizational theory, the paper suggests that further research should focus on taking these suggestions to an operational level for the benefit of FM, building clients and design teams. Furthermore, it is found that major concepts that could be considered helpful to secure operational knowledge in design, such as Soft Landings and certification schemes like DGNB, are almost absent in the selected literature. This indicates that they are not recognized, and therefore not researched, as methods for knowledge transfer. Several countries, such as US, UK, Denmark, Saudi Arabia, and Malaysia are represented in the review.

Keywords: Facilities Management, knowledge transfer, performance gap, construction management, building performance optimization.

1. INTRODUCTION

When a new built facility is handed over from construction to operation, the building owner, facilities manager or facility users frequently experience a gap between the expected performance and the actual performance. Concerning energy consumption, literature describes a reliability gap between the calculated and the actual energy consumption (Ornetzeder et al. 2016, Mills 2010). In addition to energy efficiency, other aspects of building performance have been recognized to be deficient: lack of functionality, poor indoor climate, difficulties in operation and maintenance, and poor cleaning possibilities (Jensen 2012, Hansen & Damgaard 2012).

The reduced performance in facility operation persists until changes can be implemented, though some deficiencies are likely to be permanent once the facility is in operation. Changes may consist of adjustment or replacement of parts of the technical installations, physical changes or addition in the building, and/or changes in human behaviour. The reduced building performance - and the often expensive changes needed to increase performance and bridge the gap - has a negative impact on the environment, economy, productivity, and life quality for end users and operation staff.

As awareness of the importance of sustainability is consolidating in society, policymaking and among building owners, there is an increasing demand that the building industry contributes to bring down energy consumptions (Mills 2010, Way 2005, Sunikka-Blank &

Galvin 2012). Furthermore, awareness of the importance of proper indoor climate and working environment for employees, including operation and maintenance personnel, increases. This makes continued efforts to increase building performance ever more important.

This paper is based on earlier research suggesting that integrating operational knowledge in design stages can help bridge the performance gap (Jensen 2012, Hansen & Damgaard 2012, Way 2005). Particularly The design stage in particular has been identified as crucial for two main reasons. First, difficulties in operation are often caused by faults in design, rather than faults in construction (Alhaji Mohammed & Hassanain 2010). Second, because changes are more easily made during design than during construction; during operation some changes are impossible to implement.

The importance of integrating operational knowledge in design seem acknowledged by the building industry as several concepts, for example Building Commissioning (Mills 2010), Continuous Briefing, and Post Occupancy Evaluation (POE) (Jensen 2012) include elements of knowledge transfer from operation to design. Despite these efforts, recent studies (Ornetzeder 2016) indicate that the performance gap has not yet been bridged, and transferring knowledge is not easily done.

The purpose of this study is therefore to investigate the state of the literature with respect to how knowledge can be transferred efficiently from operation to design, since this has been acknowledged as being helpful to bridge the performance gap within the building industry. By conducting a systematic literature review, we aim to clarify what current theory tells us to do to solve the problem of insufficient knowledge transfer. First, we gather a list of available tools to get an overview of practical recommendations. Second, we examine how differing theoretical fields contribute to solve the problem. This approach gives a basis for investigating if current theory fully incorporate the complexity of the phenomenon of knowledge transfer from operation to design. The study is of relevance, because it puts forward an explanation for the failure of successive attempts to enable knowledge transfer in building projects and thereby appoints direction for further research.

2. METHODOLOGY – A SYSTEMATIC LITERATURE REVIEW

A systematic literature review was conducted to assess how the literature describes knowledge transfer from building operation to design. The review is based on principles outlined in Okoli and Schabram (2010) and Webster and Watson (2002). Okali and Schabram (2010) provide “eight steps for systematic review” and Webster and Watson (2002) provide guidelines on searching for literature in three directions: using keywords, following the references in the selected papers, and then looking for papers that cited the selected papers (keyword, backward and forward).

In order to identify the most appropriate words to apply to the keyword search, a ‘word counter’ was used on a few highly relevant articles already known to the authors (title, keywords and abstract). To this end, the 25 most frequently used words were grouped based on their similarities in the meaning and then applied as keywords for the search of the relevant articles (Table 1).

A keyword search with Boolean operators (Table 1) was conducted within the Scopus multidisciplinary database, provided by Elsevier. A certain degree of testing the search strategy was needed, leading to adjustments. Having successfully conducted a simple test searching for highly relevant articles already known to the authors, Scopus was found suitable and, with access to more than 50 million records, sufficient for this review. The search returned 264 documents.

Table 1: Boolean Operators

Search terms							
knowledge	*and*	**transfer**	*and*	**"building operation"**	*and*	**"building design"**
Or "Know how"		*Or* sharing *Or* "feed back" *Or* management *Or* integration		*Or* "operations and maintenance" *Or* "facilities management" *Or* "facility management" *Or* FM		*Or* construction *Or* "hand over" *Or* Design	

From here, the following practical screens were used:

- Language: English.
- Sources: Peer reviewed articles. Books were omitted because research is often published in articles alongside books. Conference papers were also omitted, as they turned out upon examination to be either irrelevant or publications identified as earlier work to some of the included papers.
- Date: papers published between 2007 to 2017 were included. Searching backward allowed for older publications to be included.
- Setting: Several research fields not relevant for this study were excluded (e.g., agriculture, microbiology and nursing.)

The above practical screens reduced the search results to 93 articles.

The authors went through title, keywords and abstract of the 93 articles to determine their relevance to the original research question. After the relevancy check, there were 8 accessible relevant papers. Three additional articles were identified from a backwards search (the forward search did not bring any new articles to the review), thus the search resulted in 11 articles for the analysis (Table 2).

A matrix for analysing and categorizing the articles were made and included: reliability, research field, aim, knowledge transfer tools, stakeholders, stage, aspect of sustainability, property type, research method, data type, theoretical framework, and landmark articles.

Table 2: List of reviewed articles

No.	Year	Search strategy	Author(s)	Country/Region	Journal
1	2017	Key word search	Chew et al.	Singapore	Facilities
2	2015	Key word search	Ganisen et. al.	Malaysia/India	Jurnal Teknologi
3	2015	Backwards	Göçer et al.	Turkey/US	Building and Environment
4	2013	Key word search	Meng	UK	Journal of Performance of Constructed Facilities
5	2012	Key word search	Jensen	Denmark	Architectural Engineering and Design Management
6	2012	Key word search	Menezes et al.	UK	Applied Energy
7	2011	Key word search	Chandra and Loosemore	Australia/Indonesia	Construction Management and Economics
8	2010	Backwards	Alhaji and Hassanain	Saudi Arabia	The Built & Human Environment Review
9	2009	Key word search	Jensen	Denmark	Architectural Engineering and Design Management,
10	2007	Key word search	Richardson and Lynes	Canada	International Journal of Sustainability in Higher Education
11	2003	Backwards	Erdener	US	Journal of Performance of Constructed Facilities

3. FINDINGS

Table 2 is a short list of the 11 articles, supplemented by Appendix A, providing a brief presentation of the articles and their main findings. Table 3 shows the tools identified within the 11 articles.

The topic is covered by journals representing a wide range of research fields, and only two journals are represented by more than one article (Table 2). This allows an analysis of the topic from various research fields and perspectives. A regional screen was not applied to the search, and the articles originate from various regions (table 2): UK (two articles), Denmark (two articles), Singapore, Malaysia/India, Turkey and US, Australia/Indonesia, Saudi Arabia, Canada and US.

The theoretical frameworks used in the articles can be divided into three categories, along a continuum. At one side is what we categorize as the socio-idealists and at the other side is the technical-idealist. In the middle we find frameworks of Facilities Management (FM) and Construction Management (CM) that borrow theories from both side.

Chandra and Loosemore (2011) is the purest example of the socio-idealists. One of several causes for difficulties in building design is described as follows: “A new hospital project becomes a challenging arena where all the inherent tensions that exist in the health sector are

acted out", and consequently, the project team must "work within this highly emotive environment and within subtle, existing and often assumed power structures (…)". Having this as a starting point, Chandra & Loosemore uses frameworks and terms from psychology, organizational theory, cultural theory and knowledge management. Based on qualitative data, they give general suggestions for changes in the briefing stage. They suggest creating opportunities for constructive conflicts and encourage a briefing process with the end users in a leading role.

On the opposite end of the spectrum, Menezes et al. (2012) use quantitative data to propose a technical solution to bridge the performance gap. By describing the challenges of the design team they state:"Currently, there is a significant lack of information concerning the actual energy performance of our existing building stock." As Menezes et al. (2012) do not identify the same causes of the problem as Chandra and Loosemore (2011), their research is based on different theories. Menezes et al. use a framework of engineering, particularly the field of energy calculations. Changes to Post Occupancy Evaluation (POE), which, to some degree, is already implemented in the building industry, are suggested to give data that is far more accurate than today, leading to more precise predictions of future building's actual performance.

The majority of the articles are between these two presented categories, and focuses mainly on theory of CM, FM or both, borrowing theories from socio-idealists and technical-idealists. There is a tendency that the more the research leans to the socio-idealistic side, the less specific the recommendations are, and likewise, the more the research has a technical approach, the more specific the recommendations are.

Meng (2013) is an example of research of CM and FM, borrowing mainly from the socio-idealist fields. Meng (2013) presents a qualitative study including a literature review and interviews from more than 30 experts, leading to an identification of barriers to early FM involvement in design. Suggestions to overcome these barriers include "more attention to FM role" and "dialogue and good communication". This gives a thorough understanding of the barriers and underlying human mechanism, and points in a certain direction for solutions. However, it then leaves it up to the practitioners to sort out how to do in practice.

Two articles in the review represent Jensen, and the articles place themselves between the socio-idealist and technical-idealist. Based on literature review, case studies, a larger research project, and his own experience, Jensen (2009; 2012) provides a methodology for knowledge transfer in building projects. Using a theoretical framework of knowledge management, he lists a number of tools to enable knowledge transfer in a building project, including Commissioning, Projects Reviews, and Design, Build and Operate. These suggestions are on the technical-idealistic side and go beyond pointing a direction, as they are solutions that can be adopted by the building client. On the socio-idealistic side, he uses the example of the poor result of Danish regulation on the use of Life Cycle Cost (LCC) in public building projects, suggesting that "awareness" can be a more effective tool than "regulation", and furthermore he emphasises that the building client must take leadership of implementing initiatives to transfer knowledge from operation to design.

Göçer et al. (2015) is an example of research of CM, borrowing mainly from the technical-idealistic side. Göçer suggests, based on previous studies, that the feedback method POE should be further developed regarding the stages included as well as the methods and data used. They find an extended use of BIM (Building Information Modelling), including spatial

mapping, suitable to enable knowledge transfer from operation to design, bringing the predictions closer to actual building performance.

In addition to the differences in how concrete the recommendations of the articles are, there is also a difference in the approach to the problem. While the majority of the articles are concerned with how building performance can increase aligning of expectation and reality, two articles focus on getting the predictions corrected to align expectations and reality. In other words, it becomes a question of whether the aim of the recommendations in the article are to raise the performance or to lower the expectations. While none of the articles explicitly recommends lowering performance targets, there is nevertheless a tendency, that the more technical the framework used, the more the focus shifts towards correcting the calculations, rather than increasing performance. Correcting the calculation is, off course, expected to predict a lack of performance as early as possible, allowing the design team to make changes to the design, and leading, in the end, to higher performance.

The tools identified in the review are presented in Table 3. The term 'tool' is used on all the practical recommendations on optimizing transfer of operational knowledge to design. Not all of the articles are dealing with the topic in such a precise manner. For instance, Richardson and Lynes (2007) are concerned with how decisions on more green buildings on a university campus can be increased by including FM knowledge in decision-making. Nevertheless, the recommendations are compiled to provide an overview of the identified tools. Vague recommendations such as "more attention to FM", "good communication" (Meng 2013) and "increase transparency and communication" (Richardson & Lynes 2007) are left out as they are not identified as tools by the authors. Some tools have slighty different names in the articles, and with the risk of leaving out important differences, they have been put together with very similar tools to make a list of the main tools found.

Table 3: List of the identified tools.

Tools
a) Green maintainability protocol (Chew 2017) b) LCC (Chew e2017, Meng 2013, Jensen 2009, Jensen 2012) c) Financial forecast/FM budgeting in the design stage (Ganisen et al. 2015, Jensen 2009) d) List of environmental variables to consider in design stage (Ganisen et al. 2015) e) POE (Göçer et al. 2015, Menezes et al. 2012, Alhaji Mohammed & Hassanain 2010) f) PPP (Meng 2013, Jensen 2012), including PFI (Meng 2011) g) Continues Commissioning (Jensen 2012) h) Continuous briefing (Jensen 2009 and 2012) i) Detailed briefing, including guidelines, checklists, databases (Jensen 2009 and 2012), j) CAFM (Jensen 2009) k) Digital handover (Jensen 2009) l) Project reviews (Jensen 2009 and 2012, Alhaji Mohammed & Hassanain 2010) m) Regulation (Jensen 2009 and 2012) n) Design, build and Operate (Jensen 2009 and 2012) o) Contractor responsible for O&M (Jensen 2012) p) Technical Due Diligence (Jensen 2012) q) Building client guidelines and measureable quantitate targets (policy) (Richardson & Lynes 2007)

r) Briefly mentioned: LEED (Chew et. al. 2017, Göçer et al. 2015)
s) Briefly mentioned: BREEAM (Chew et al. 2017)
t) Briefly mentioned: Soft Landings (as a route to the use of POE) (Göçer et al. 2015)

4. DISCUSSION

Surprisingly, the articles seldomly mention certification schemes like LEED, BREEAM and DGNB (Chew 2017, Goçer et al. 2015), even though these schemes receive a lot of attention in practice. Soft Landings and commissioning are also discussed little within the articles (Göçer et al. 2015, Jensen 2012). It indicates that these concepts are not recognised and researched as tools for knowledge transfer. This is problematic, because important issues relating to knowledge transfer may then not be considered.

Several of the articles describe the contributions of FM to building projects. Alhaji Mohammed & Hassanain (2010) describe a very comprehensive role, giving FM a coordinating and approving role. Ganisen et al. (2015) support this comprehensive role: "During design phase Facility manager can provide accurate information on long term operational cost, introduce feasible design for building facilities, and guide with construction alternatives (…)". Further research is needed to better understand the skills and competences FM personal should obtain to fulfil these increasing roles in building projects. In addition to that, it would be of great interest to investigate if the Facility Managers currently possess these skills, and if not; what is needed before the extended role of FM in building design is even possible.

Jensen (2009, 2012) highlights the building client as an important stakeholder when it comes to ensuring knowledge transfer. Facilities Management are, by many suggested to be able to provide great insight to new building projects (Jensen 2009 and 2012, Chew 2017, Meng 2013), and also the users are suggested to play a leading role (Chandra and Loosemore 2011). Both FM and the building client are referred to as a person or a unit. In reality, both FM and the building client, as well as the users, may be an entire organization and the necessary knowledge can be spread on sometimes hundreds of persons. Consequently, this paper suggests that future research investigates how FM as an organization can fulfil this important role in the knowledge transfer in an effective and valuable manner.

Many fields have potential to shed light on the problem of insufficient knowledge transfer from building operation to design. Therefore, new insights may be gained from studying other industries for inspiration for practical recommendations. This includes industries that have succeeded in knowledge communication between different cultures and industries experienced with knowledge management. Our next step in researching the insufficient transfer of knowledge in building projects includes comparative case studies of different industries.

5. CONCLUSION

There are currently two opposite trends in the research of knowledge transfer from building operation to design. On one hand, the socio-idealists looking at cultural and organizational theories for answers, and on the other hand, the technical-idealists looking at rational

engineering frameworks for answers. The paper identifies a gap between the two, as there are none or only very few practical directions to how strong leadership, constructive conflicts, etc., can be carried out in a design process, and opposite; none or only few directions on how for instance proper communication can be ensured when using tools like POE, project review etc. Based on that, this paper recommends, that further research should aim to make the recommendation of the socio-idealists instrumental, and include such recommendations in the identified tools like projects reviews, POE, commissioning etc.

A list of available tools has been gathered from the reviewed literature, confirming that a number of tools have already been developed and, to various degree, implemented in the building industry. Unfortunately, there are, as described in discussion, reasons to believe that some tools to ensure knowledge transfer are absent from the list. Apparently, they are not described as methods to enable knowledge transfer, and will consequently not appear in the search result for this review. Furthermore, the list lacks input from the socio-idealists, as their recommendations are identified as "awareness" rather than tools.

Our overall critique of the current theory of knowledge transfer from building operation to design is that studies in the literature generally underestimate the complexity of the problem. There is currently a lack of interdisciplinary studies that combine theories of organization, communication and knowledge management with theories of FM and CM that lead to practical directions. Therefore, the authors recommend further research to seek to combine the two opposite trends and turning 'awareness' into practical directions for the benefit of building clients, design teams, facility managers, building users, and the environment.

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Appendix A; Brief description of the 11 reviewed articles, published 2003- 2017.

Author(s)	**Title of the article**	**Brief description**
Chew, M. Y. L. et al.	Developing a research framework for the green maintainability of buildings.	Based on a comprehensive study of 41 articles, Chew concludes that there is little research on the maintainability of green building and introduces the concept of 'green maintainability". Chew states, that: "Researchers have emphasized the main causes that lead to building operations and maintenance problems are faulty design and maintenance -related defects". Chew presents the idea of a green maintainability protocol as a tool to consider the maintainability of green buildings at the design stage.
Ganisen, S.et. al.	Facility management variables that influence sustainability of building facilities.	A comprehensive literature review leads to the identification of a large set of FM criteria that influences sustainability in buildings. The criteria is divided in 7 categories and suggestions on FM contributions are provided. Examples of categories are O&M, Financial Management (including LCA), Environmental management and, health and safety management.
Özgür G. et al.	Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance	By reviewing improvements made on the existing concept of POE, this article sets out 'a new vision for how future post-occupancy evaluation can close the building performance feedback loop (…)'. Integrating the use of BIM and GIS, and establishing a communication platform is suggested to improve POE and increase the share of quantitative data. According to the author, POE has the potential of bridging the performance gap by providing more realistic input to energy models. Ösgür is also concerned with more realistic data to bridge the gap.
Meng, X.	Involvement of facilities management specialists in building design: United kingdom experience.	This study investigates 'early involvement of FM' through 31 expert interviews with industrial practitioners. Conclusions are, that despite the increasing acknowledgement of the benefits of early involvement of FM, resistance in practice is remains. Meng categorizes barriers in their relations to stakeholders, and makes suggestions to overcome the barriers, e.g. ' more attention to FM role', 'highlight of whole life costing' and, 'dialogue and good communication'.
Jensen, P. A.	Knowledge transfer from facilities management to building projects: A typology of transfer mechanisms.	In this article, Jensen presents a typology of mechanism of knowledge transfer from FM to building projects, suggesting that multiple strategies are needed simultaneously. 8 concepts are highlighted as serving different type of transfer, e.g. commissioning, project reviews, and regulation.
Menezes, A. C. et al.	Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap.	This article, based on case studies, argues, that the performance gap between predicted and actual energy performance, is best bridged by an extended use of POE. POE is recommended as an effective way of ensuring the needed, and currently missing, feedback from post occupancy to design. The purpose is to adjust the predictions to reality, rather than adjust reality to predictions.
Chandra, V., & Loosemore, M.	Communicating about organizational culture in the briefing process: Case study of a hospital project.	Based on case studies of 2 simultaneously briefing process (two parts of the same hospital building project), Chandra finds that the present briefing process is far too focused on physical needs and technical issues. Chandra argues that the building project will profit from a briefing process that encourage constructive conflicts providing deeper cultural learning. This acquires adequate time and skills, and can advantageously be led by the end users as 'custodians of cultural knowledge'.
Alhaji M. and. Hassanain M.A.	Towards Improvement in Facilities Operation and Maintenance through Feedback to the Design Team.	In this article, definitions for the different stakeholders in current building design are listed and a new definition for FM in design is suggested giving FM a central and coordinating role within 'the integrated design team'. FM contribution and feedback to each part of the design team, together with approval of design by FM are key elements.
Jensen, P. A.	Design integration of facilities management: A challenge of knowledge transfer.	This article can be seen as a forerunner for the article by the same author published 3 years later also included in this review. The building client is giving the leading role to ensuring, that 'the considerations for operation and sustainability are taken seriously by the design team'. Codification of knowledge is one of four mechanism Jensen argues results in increase of transfer of knowledge. Jensen furthermore discusses the effectiveness of use of power in contrary to awareness and argues that competences of the FM personnel involved in design is important for several reasons.
Richardson, G. R. A., & Lynes, J. K.	Institutional motivations and barriers to the construction of green buildings on campus: A case study of the university of Waterloo, Ontario.	This Article study the barrier and motivations to the construction of green buildings, suggesting that four key ingredients are needed for successful green buildings. Based on 13 interviews and document analysis on one university Campus four ingredients related to decision making prior to design are defined: Strong leadership, quantitative sustainable targets, facilitation of collaboration, and increased communication.
Erdener, E.	Linking Programming and Design with Facilities Management.	Erdener suggest that programming provides great opportunity of linking different stakeholders in the building project, and suggest FM as a strategic resource and partner in the process. A modified framework for the construction management of a facility is presented, suggested to replace the present and well known framework of predesign, design, construction and post occupancy.